

AG Cross Ex

# Transforming the Local Exchange Network: Analyses and Forecasts of Technology Change

---

*Lawrence K. Vanston, Ph.D.*

AG Cross 02-0864  
32  
3-17-04 CUC

1994 Edition

## Executive Summary

through 1995. Finally, some of the outside plant forecasts rely on previous forecasts of the demand for wideband and broadband digital services.

### Forecasts for the Outside Plant

The major technology change in the outside plant is the adoption of fiber optics in all parts of the network. The interoffice plant is already largely fiber (74% of circuits at year-end 1993) and, by 2000, we forecast the interoffice to be 98% fiber. Fiber adoption in the feeder network has progressed more slowly than in the interoffice network, with about 11% of access lines on fiber feeder at year-end 1993. We forecast that, by 1998, one-fourth of access lines will be served by fiber feeder. Thereafter, adoption of fiber in the feeder is expected to be determined largely by the adoption of Fiber in the Loop (FITL) systems that employ fiber in both feeder and distribution.<sup>1</sup> We use a scenario-based approach for addressing the adoption of distribution fiber. The following table summarizes the scenarios:

Year	<i>Percentage of Access Lines on Distribution Fiber</i>		
	Early Scenario	Middle Scenario	Late Scenario
1998	10%	5%	1%
2000	28%	15%	2%
2005	91%	59%	27%
2010	100%	92%	85%
2015	100%	99%	99%

Our analysis indicates that the most likely pattern of adoption for distribution fiber falls between the early and middle scenarios, with companies that aggressively compete in video services tending toward the early scenario.

Exhibit ES.1 illustrates the outside plant forecasts in graphical form, with the markers indicating historical and planning data.

<sup>1</sup> A variety of architectures are available for distribution fiber, which may use fiber, copper pairs, radio, or coaxial cable for the final link to the customer. An industry consensus has yet to develop on which architecture will ultimately dominate and, for this study, we have not distinguished among them. Each implies the displacement of most, if not all, copper cable in the distribution network.

## Executive Summary

- The replacement of existing digital switches by a new architecture optimized for ATM beginning in the early 2000s and completed by 2015, as shown in Exhibit ES.3.

### Equipment Lives and Investment Requirements

Exhibit ES.4 summarizes our estimates of the Average Remaining Lives (ARLs) of existing investment in place at year-end 1993. These estimates are based on the above forecasts of new technology adoption. This approach is superior to traditional mortality-based depreciation analysis when technological obsolescence is the primary driver for retirements.

#### Exhibit ES.4 Summary of Average Remaining Lives

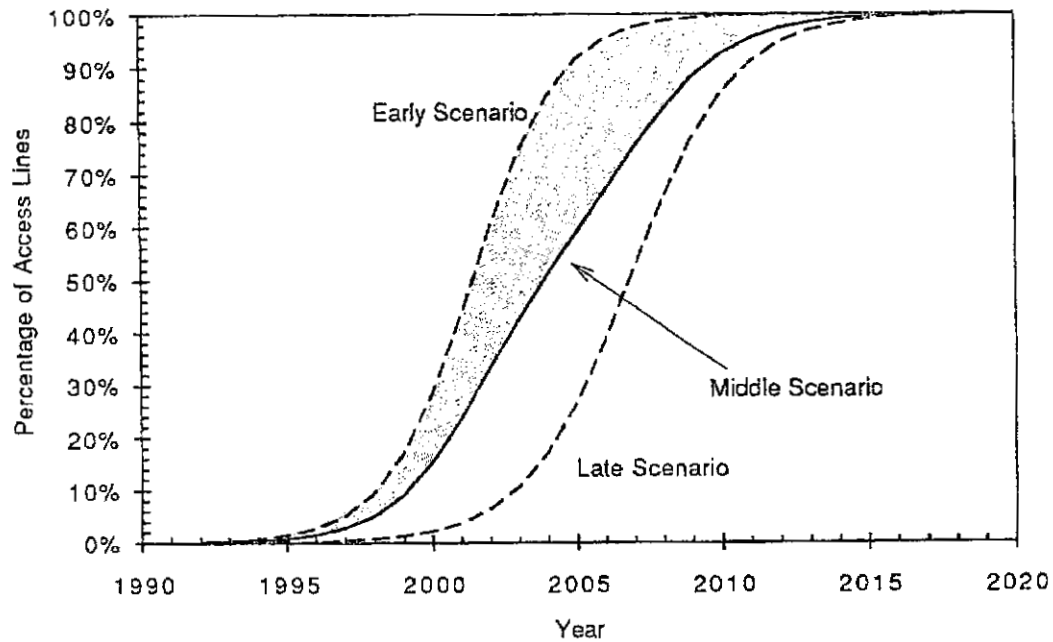
Category	% of Total Investment	Average Remaining Life (1/1/94)
<b>Outside Plant</b>		
<i>Copper Cable</i>		
Interoffice	1.2%	3.1 years
Feeder	14.6%	8.5 years
Distribution	16.2%	8.4-11.1 years
<i>Fiber Cable</i>		
All	4.0%	16 years
<b>Circuit Equipment</b>		
Non-SONET	23.0%	4.4 years
<b>Switching</b>		
Analog	6.6%	2.9 years
Digital	15.4%	7.0 years
<b>Composite</b>	<b>81.0%</b>	<b>6.9-7.4 years</b>

Source: Technology Futures, Inc.

# Fiber Adoption in the Outside Plant

## Exhibit 3.14

### The Adoption of Distribution Fiber—Three Scenarios



Source: Technology Futures, Inc.

## Chapter Three

## Exhibit 3.15

## Provision of Digital Services on Fiber—Percentage of Access Lines

Year	Wideband	Availability Required to serve	Broadband Demand	Availability Required to serve	Average Scenario			
	Demand	WB Demand		BB Demand	Fiber Availability	WB Demand served on Fiber	WB Demand not served on Fiber	WB Avail not served on Fiber
1992	0.0%	0.2%		0.0%	0.1%	0.0%	0.0%	0.1%
1993	0.0%	0.4%		0.0%	0.2%	0.0%	0.0%	0.2%
1994	0.2%	0.8%		0.1%	0.4%	0.1%	0.1%	0.3%
1995	0.6%	1.4%		0.1%	0.8%	0.3%	0.3%	0.7%
1996	1.2%	2.8%		0.2%	1.5%	0.7%	0.5%	1.3%
1997	2.3%	5.2%		0.4%	2.8%	1.2%	1.1%	2.4%
1998	3.9%	9.6%	0.3%	0.7%	5.2%	2.1%	1.8%	4.4%
1999	6.7%	17.0%	0.5%	1.3%	9.1%	3.6%	3.1%	7.9%
2000	10.5%	28.4%	0.9%	2.2%	15.3%	5.7%	4.8%	13.1%
2001	15.1%	43.4%	1.6%	3.8%	23.6%	8.2%	6.9%	19.8%
2002	20.4%	59.8%	2.8%	6.4%	33.1%	11.3%	9.1%	26.7%
2003	26.4%	74.2%	4.5%	10.7%	42.4%	15.1%	11.3%	31.8%
2004	32.1%	84.8%	7.1%	17.2%	51.0%	19.3%	12.8%	33.8%
2005	36.5%	91.5%	10.6%	26.6%	59.0%	23.6%	12.9%	32.4%
2006	39.0%	95.4%	15.0%	38.7%	67.1%	27.4%	11.6%	28.4%
2007	39.5%	97.6%	20.4%	52.4%	75.0%	30.4%	9.1%	22.6%
2008	38.2%	98.7%	26.5%	65.7%	82.2%	31.8%	6.4%	16.5%
2009	35.5%	99.3%	33.0%	77.0%	88.2%	31.5%	4.0%	11.2%
2010	32.1%		39.7%	85.3%	92.5%	29.0%	2.3%	7.2%
2011	28.4%		46.1%	91.0%	95.4%	27.1%	1.3%	4.4%
2012	24.9%		51.9%	94.6%	97.3%	24.2%	0.7%	2.6%
2013	21.6%		57.0%	96.9%	98.4%	21.3%	0.3%	1.5%
2014	18.9%		61.3%	98.2%	99.1%	18.7%	0.2%	0.9%
2015	16.4%		64.7%	98.9%	99.5%	16.3%	0.1%	0.5%
2016	15.1%		67.5%	99.4%				

Source: Technology Futures, Inc.

The middle scenario represents a balancing act for the LECs. If they over-invest in upgrading copper, they risk entering the next century with an obsolete network, after having sunk large amounts of money into equipment to enhance the copper technology. On the other hand, they cannot get fiber to everyone simultaneously, and, even if they could, it might not be the best plan financially. The middle scenario avoids the two extremes, with wideband services being provided on copper in the early years, then migrating to fiber as demand increases and costs continue to fall.

## Fiber Adoption in the Outside Plant

Exhibits 3.16 and 3.17 illustrate some implications of the middle scenario. The left two curves in Exhibit 3.16 show fiber adoption under the early and middle scenarios; the difference between them is the shortfall, or gap, in the amount of fiber needed to serve wideband demand. The right two curves show wideband demand. The solid curve shows the percentage of access lines serving wideband customers and the dashed curve shows the percentage that could be served by fiber, given the middle scenario. The difference between the two is the percentage of total access lines that need wideband service but cannot be served on fiber under the middle scenario because of the gap in availability. This difference would have to be provided for by ADSL/HDSL technology, left unserved, or left to competitors.

Exhibit 3.17 plots the percentage of subscribers served on ADSL/HDSL technology under the middle scenario, as well as the required availability of ADSL/HDSL. Under the middle scenario, a maximum of 13% of all access lines would be served by ADSL/HDSL in 2005, and up to 34% of all access lines would need to be ADSL/HDSL-ready.<sup>9</sup>

Adopting fiber more slowly than in the middle scenario would require a greater investment in ADSL/HDSL and divert excessive resources away from the preferable, long-term technology—FITL. With the competition deploying more efficient technology and offering higher-quality services, this would be a dangerous course. For this reason, we believe that the middle scenario implies the *maximum* rational deployment of ADSL/HDSL and that the “late” scenario is not a reasonable choice.

However, this does not mean that the middle scenario is necessarily the best choice either. For companies that want to realistically compete in the provision of standard cable television services, as opposed to what has been called VCR-quality interactive services, the early scenario is better. Also, regardless of cable television services, many companies will adopt fiber strategies that will be much closer to early scenario because, given the increasingly competitive nature of the industry, this is a less risky strategy. For these reasons, we believe that the likely industry FITL adoption pattern will fall between the early and middle scenarios.

---

<sup>9</sup> Although this does not necessarily mean that the entire 34% must be equipped with ADSL/HDSL electronics, it does mean that this percentage of copper plant must be properly conditioned and administered for ADSL, and that a sufficient inventory of electronics be kept online.

## Fiber Adoption in the Outside Plant

### Exhibit 3.30 Distribution Copper Survivors

Year	Early Scenario			Late Scenario			Middle Scenario				
	Pct of Access Lines		Pct of Copper Lines Surviving	Pct of Access Lines		Pct of Copper Lines Surviving	Pct of Access Lines		Pct of Copper Lines Surviving		
	Fiber	Copper		Fiber	Copper		Fiber	Copper			
1993	0.4%	99.6%	100.0%	0.0%	100.0%	100.0%	0.2%	99.8%	100.0%		
1994	0.8%	99.2%	99.6%	0.1%	99.9%	100.0%	0.4%	99.6%	99.8%		
1995	1.4%	98.6%	98.9%	0.1%	99.9%	99.9%	0.8%	99.2%	99.4%		
1996	2.8%	97.2%	97.6%	0.2%	99.8%	99.8%	1.5%	98.5%	98.7%		
1997	5.2%	94.8%	95.2%	0.4%	99.6%	99.6%	2.8%	97.2%	97.4%		
1998	9.6%	90.4%	90.8%	0.7%	99.3%	99.3%	5.2%	94.8%	95.0%		
1999	17.0%	83.0%	83.3%	1.3%	98.7%	98.8%	9.1%	90.9%	91.1%		
2000	28.4%	71.6%	71.9%	2.2%	97.8%	97.8%	15.3%	84.7%	84.9%		
2001	43.4%	56.6%	56.8%	3.8%	96.2%	96.3%	23.6%	76.4%	76.6%		
2002	59.8%	40.2%	40.4%	6.4%	93.6%	93.6%	33.1%	66.9%	67.1%		
2003	74.2%	25.8%	25.9%	10.7%	89.3%	89.4%	42.4%	57.6%	57.7%		
2004	84.8%	15.2%	15.3%	17.2%	82.8%	82.8%	51.0%	49.0%	49.1%		
2005	91.5%	8.5%	8.5%	26.6%	73.4%	73.4%	59.0%	41.0%	41.0%		
2006	95.4%	4.6%	4.6%	38.7%	61.3%	61.3%	67.1%	32.9%	33.0%		
2007	97.6%	2.4%	2.4%	52.4%	47.6%	47.6%	75.0%	25.0%	25.1%		
2008	98.7%	1.3%	1.3%	65.7%	34.3%	34.3%	82.2%	17.8%	17.8%		
2009	99.3%	0.7%	0.7%	77.0%	23.0%	23.0%	88.2%	11.8%	11.9%		
2010	99.7%	0.3%	0.3%	85.3%	14.7%	14.7%	92.5%	7.5%	7.5%		
2011				91.0%	9.0%	9.0%	95.4%	4.6%	4.6%		
2012				94.6%	5.4%	5.4%	97.3%	2.7%	2.7%		
2013				96.9%	3.1%	3.1%	98.4%	1.6%	1.6%		
2014				98.2%	1.8%	1.8%	99.1%	0.9%	0.9%		
2015				98.9%	1.1%	1.1%	99.5%	0.5%	0.5%		
2016				99.4%	0.6%	0.6%					
Avg Remaining Life (as of 1/1/94)			8.4	Avg Remaining Life (as of 1/1/94)			13.8	Avg Remaining Life (as of 1/1/94)			11.1

Source: Technology Futures, Inc.

NOTES ON CONTRIBUTORS WILLIAM BAKER (217) 628 1937 P. 10

# Transforming the Local Exchange Network:

Analyses and Forecasts of  
Technology Change

---

*Lawrence K. Vanston, Ph.D.*

*Ray L. Hodges*

*Adrian J. Poitras*

Second Edition

**Copyright © 1997, Technology Futures, Inc.**

ISBN 1-884154-08-5

All rights reserved. Published August, 1997. No part of this report may be reproduced in any form or by any means, other than short quotes to be used in reviews, without express permission from the publisher.

Authorization to photocopy items for internal or personal use, or the internal or personal use of specific clients, is granted by Technology Futures, Inc., provided that the base fee of US\$10.00 per copy plus \$5.00 per page is paid directly to Copyright Clearance Center, 27 Congress Street, Salem, MA 01970, USA.

Printed in the United States of America.

**Published by Technology Futures, Inc.**

13740 Research Boulevard, Building C  
Austin, Texas 78750-1859  
(800) 835-3887  
(512) 258-8898  
Fax: (512) 258-0087  
Internet: <http://www.tfi.com>

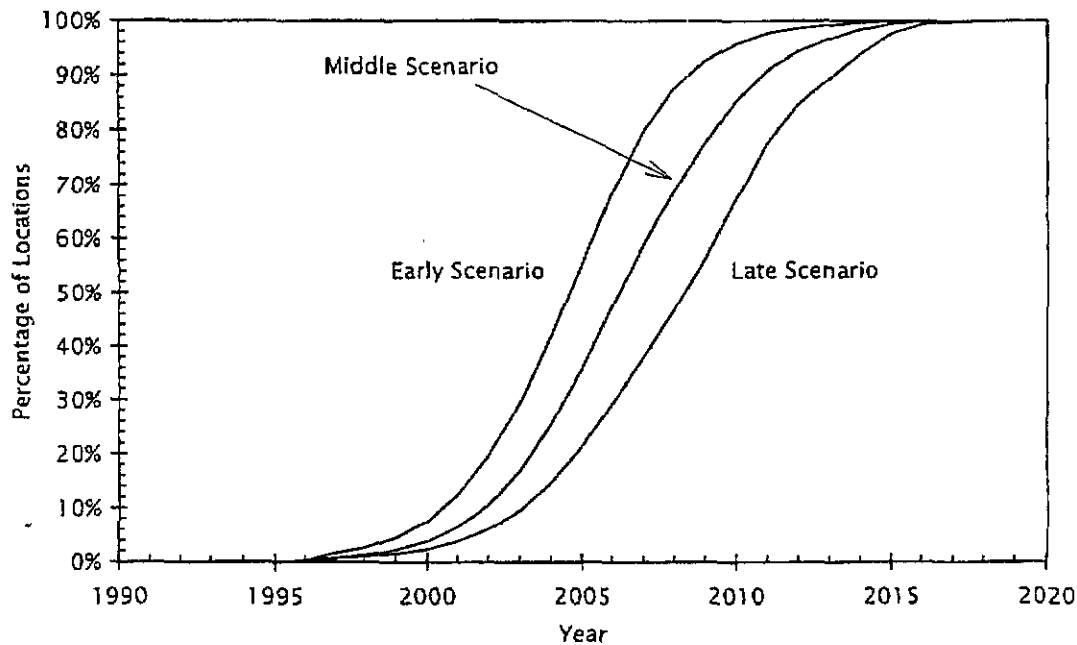
extent that would over-commit them to an obsolete copper network over the long run. Based on any number of factors—including competitive pressures, demographics, geography, mix of aerial and buried cable, corporate culture, regulatory environment, and growth—some companies will adopt FITL earlier or later.

### Circuit Equipment—The Adoption of SONET

The lives of current digital circuit equipment will be impacted by SONET equipment, along with other technology deployments. SONET will impact virtually all other circuit equipment, including modern digital and fiber optics terminal equipment. Our industry forecast for SONET adoption implies that, before 2005, essentially all currently-deployed non-SONET equipment will have been replaced by SONET equipment.

SONET is a format for organizing information on a fiber optics channel that recognizes the need for integrating different types of traffic on the same pair of fibers. Among its many advantages are standardized optical and electrical interfaces to which all suppliers must adhere. Another is that an individual information stream on a fiber channel can be efficiently separated from the rest of the information on the channel. With a SONET add-drop multiplexer, any signal can be extracted with a single piece of equipment without breaking down the whole signal. SONET add-drop multiplexers are already cost-competitive with asynchronous equipment, and soon will be commodity items that are integrated into almost every piece of circuit (and switching) equipment. This will render redundant much existing circuit equipment, including digital crossconnects and multiplexers.

Further, with SONET, carriers can mix-and-match circuit equipment so that they can use different manufacturers' equipment. This, of course, provides operational and equipment savings, as well as more competition among manufacturers. Later on, SONET interfaces will be built directly into switches, leading to even more equipment savings. Next-generation digital loop carrier systems, TR-303, will directly link to switches through SONET interfaces. From the same unit, some channels may be connected to other switches or facilities using a built-in SONET add-drop multiplexer. Circuits could be transferred from one switch to another instantaneously. This will give carriers much more flexibility when it comes to dealing with switch manufacturers. SONET will benefit customers as well as carriers. In addition to the inherent economic benefits of a more efficient network,

**Exhibit 1.4****Digital Service Availability on Fiber—All  
Households & Business Locations**

Source: Technology Futures, Inc.

The forecasts in Exhibit 1.4 are a combination of separate forecasts for homes and small, medium, and large business locations. Homes and small business locations comprise over 99% of locations and an estimated 75% of access lines. Thus, in our analysis of distribution infrastructure, we concentrate on these two segments.

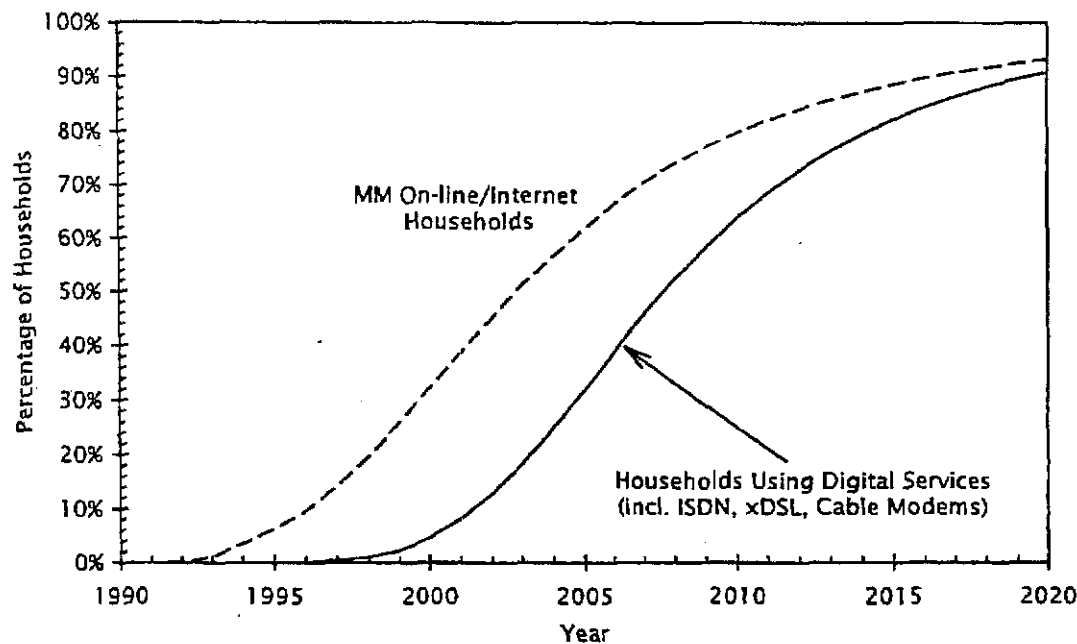
**The Home Market**

Homes alone account for over 93% of locations, so, in this summary, we focus on FITL to homes. Exhibit 1.5 shows a forecast of the percentage of households using both multimedia PCs, and on-line/Internet services. (Multimedia PCs include network PCs and Internet TVs capable of supporting multimedia. In this context, multimedia refers to the usage of a combination of text, graphics, images, audio, and/or video in an interactive computer session.) This forecast is the percentage of households likely to have bandwidth demands that are now being served by 28 Kb/s modems, but would find higher speeds and digital service very desirable if they were available and economical.

## Chapter One

Very few among these home users are subscribers to digital services today, but we expect the number to increase rapidly as Integrated Services Digital Network (ISDN) equipment and services reach the mass market, and as xDSL and cable modem services are introduced. Our forecast for the adoption of all types of home digital services, shown also in Exhibit 1.5, implies that 1% of all households will use digital services by year-end 1998, 5% by year-end 2000, and 32% by year-end 2005.

**Exhibit 1.5**  
Households Using Digital Services



Source: Technology Futures, Inc.

Although narrowband ISDN (64 Kb/s to 128 Kb/s) provides significant advantages over analog modems, the data rate is still insufficient for many multimedia applications. Thus, we expect the market will demand higher data rates. The transition to higher-speed digital services at 1.5 Mb/s and above is dependent on telephone, cable, wireless, or other companies installing the required infrastructure and making services available to residential customers. Our forecast of the availability of high-speed services, shown by the left solid line in Exhibit 1.6, indicates that 10% of households will have high-speed digital service available by year-end 2001 and 50% by year-end 2005. Subscribership is expected to follow availability as the high-speed services are rolled out with about 1% of households subscribing

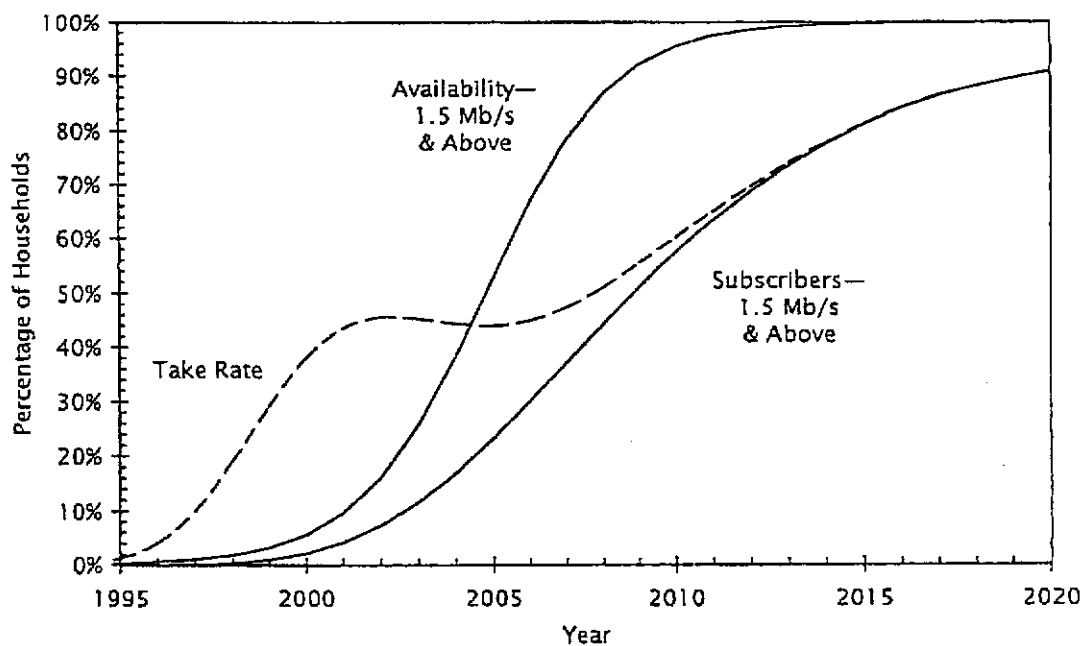
to these services by year-end 1999 and 25% by 2005, as illustrated by the right solid line in the exhibit.

So far, we have referred generically to high-speed services without specifying a particular rate. Of these, the 1.5 Mb/s offered by the most basic versions of xDSL is the lowest rate. Thus, it represents a technological threshold from the perspective of infrastructure technology. However, cable modems will offer higher access data rates, as will other versions of xDSL.

---

### Exhibit 1.6

#### Home Digital Availability and Subscribers—1.5 Mb/s & Above



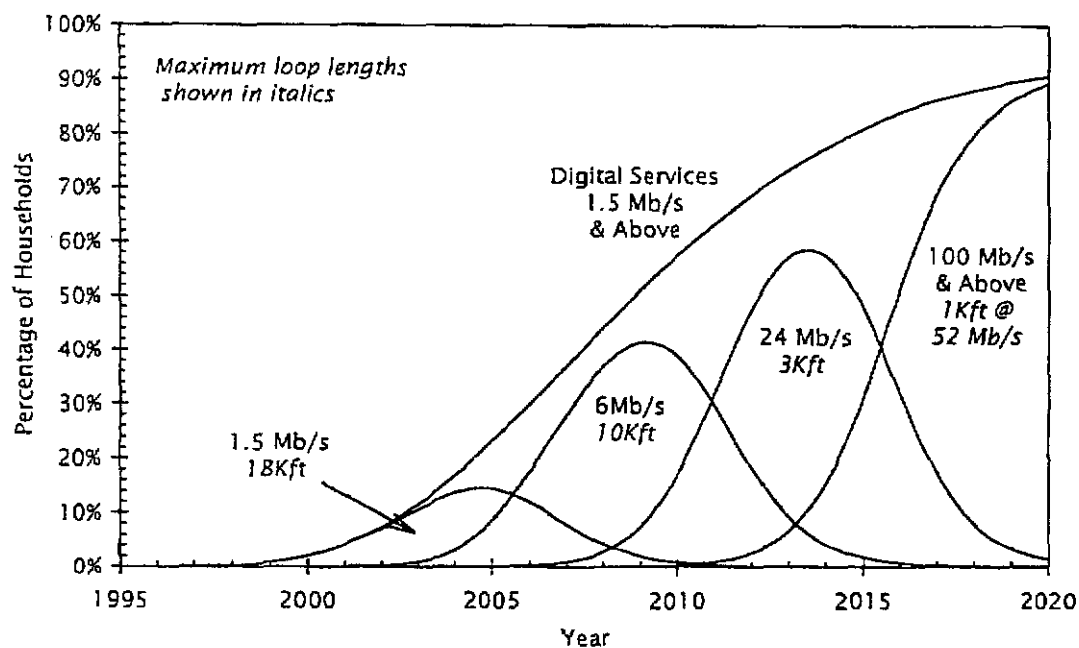
Source: Technology Futures, Inc.

Because of limitations in the facilities of Internet service providers and the Internet backbone, 1.5 Mb/s probably represents the *current* maximum usable bandwidth for home applications. We expect these limitations to ease over time, and we assume that the rate of performance increase is typical of the computer industry—specifically that performance roughly doubles every two years. This means that the minimum competitive rate for access providers will quadruple roughly every four years. We implement this principle in our forecasting by

## Chapter One

assuming that the industry progresses through several generations of data rates similar to what we have seen for modems, with a new generation introduced every four years. Exhibit 1.7 shows our forecast of the percentage of households requiring each of these rates. The forecasts assume that, in any given year, different customers demand different minimum rates, because they are different in their applications, perceptions, and willingness to pay. However, as with computers, the expectations of all users increase as the technology improves. The forecasts indicate that 1.5 Mb/s will meet the typical user's expectations until about 2005, that 6 Mb/s will do so until about 2010, then 24 Mb/s until 2015, and finally 100 Mb/s thereafter. These forecasts reflect a total life cycle of 10 years for each generation, typical for computer equipment or telephone circuit electronics.

---

**Exhibit 1.7****Households Using Digital Services—  
Minimum Competitive Data Rates**

Source: Technology Futures, Inc.

While FITL architectures provide an excellent vehicle for the provision of high-speed digital services, as well as offering intrinsic cost and operational advantages, the advantage of xDSL lies in its applicability on existing copper cable at certain combinations of data rate and distance. Exhibit 1.7 also shows for each

rate the maximum copper cable length when xDSL is used to provide digital service. LECs have choices, reflected in our three scenarios, regarding fiber and xDSL that involve the balancing of short-term and long-term considerations.

The early scenario assumes that all high-speed digital services (1.5 Mb/s and above) are served on FITL systems. Thus, the percentage of households served on fiber is the same as the availability forecast for high-speed digital services that was shown in Exhibit 1.5. The late scenario assumes maximum use of xDSL, subject to the loop length limitations shown in Exhibit 1.7. The combination of the approximate distribution of loop lengths and the xDSL loop-length limitations imply that, under the late scenario, about 20% of 1.5 Mb/s subscribers, 50% of 6 Mb/s subscribers, and 87.5% of 24 Mb/s subscribers would need to be served on FITL, in spite of the availability of xDSL.<sup>9</sup> The late scenario reflects the impact of the transition to higher bandwidths, shown in Exhibit 1.7, which forces the migration of a growing percentage of customers to FITL. For 100 Mb/s, the late scenario assumes 100% FITL.

The middle scenario assumes a mixed strategy that most resembles the late scenario in the early years and the early scenario in the later years. This maximizes the value of xDSL in providing service to customers, but allows LECs to avoid massive fiber infrastructure investments when penetration levels are relatively low. It maximizes the value of fiber later when penetration levels make such fiber infrastructure investments easier to justify.

### Summary of FITL Forecasts

A similar analysis was performed for small business locations, again resulting in three scenarios that depend on xDSL strategy. The FITL forecast for medium business locations was based on a projection of the ongoing technology substitution of fiber for copper. Most large business locations are served by fiber already. Combining these resulted in the three scenarios that were shown in Exhibit 1.4.

Based on a balance of long-run and short-run considerations, we believe that most LECs will follow a path of FITL adoption between the early and middle scenarios. These companies will make some use of copper-based xDSL, but not to the

---

<sup>9</sup> This interpretation assumes that customers are served by xDSL directly from the central office. An alternative is to connect distant customers to remote terminals that bring the xDSL electronics closer to the customer. Since these will have to be brought closer and closer as data rates increase, more and more copper will be displaced by fiber. For companies that choose to implement xDSL this way, the forecasts can be reinterpreted as the proportional impact on copper investment.